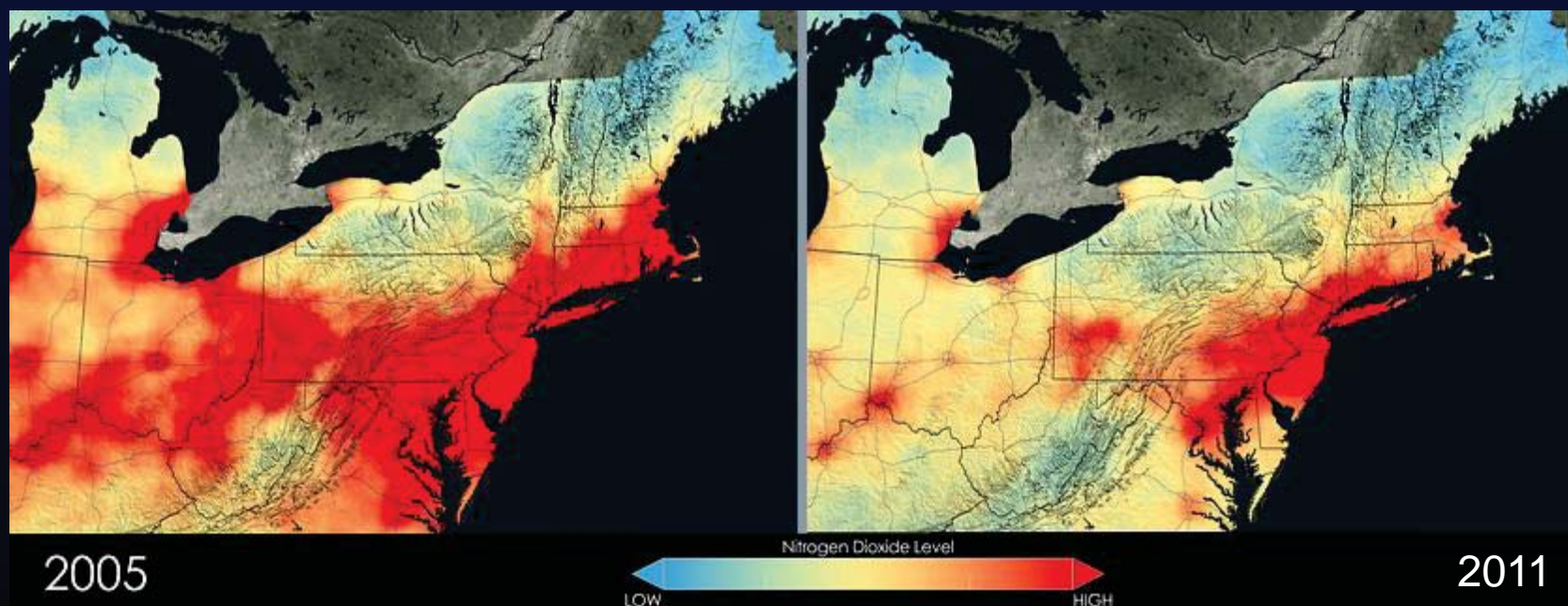


Nitrogen dioxide trend over the United States: The view from the ground, the view from space

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Federal NO_x reduction program

- 1998 NO_x State Implementation Plan (SIP) Call
- 2005 Clean Air Interstate Rule (CAIR)
- 2011 Cross-State Air Pollution Rule (CSAPR)
 - ~68% decrease in NO_x emissions from EGU since late 1990s
- Clean Air Act Amendments (CAAA) of 1990
 - ~43% decrease in NO_x emissions from mobile sources since late 1990s

Duncan, B.N., Y. Yoshida, B. de Foy, L.N. Lamsal, D. Streets, Zifeng Lu, K. E. Pickering, and N. A. Krotkov, the observed response of the Ozone Monitoring Instrument (OMI) NO₂ column to NO_x emission controls on power plants in the United States: 2005–2011, *Atmos. Environ.*, 81, 102–111, 2013.

Tong, D., L.N. Lamsal, L. Pan, H. Kim, P. Lee, T. Chai, K.E. Pickering, Long-term NO_x trends over large cities in the United States: Intercomparison of satellite retrievals, ground observations, and emission inventories, *Atmos. Env.*, 2014, under review.

Lamsal, L.N., B.N. Duncan, Y. Yoshida, N.A. Krotkov: U.S. regional and urban nitrogen dioxide trends (2005–2013): Linking high-resolution satellite tropospheric column data to AQS surface observations, 2014, in preparation.

Research questions

- How do NO₂ trends from OMI and surface monitors (EPA/AQS) compare?
- How is the pace of NO₂ reduction?
- Do we expect NO₂ column and surface concentration exhibit same trend?
- Do AQS (molybdenum converter) monitors offer actual NO₂ trend?
- How do a-priori NO₂ profiles used in retrievals affect satellite-derived trend?
- What are the trends over major metro areas and power plants?

Analysis of time series: 2005–2013

$$Y_t = Y_0 + Bt + A1 \cdot \cos(2\pi t) + A2 \cdot \sin(2\pi t) + N_t$$

= **constant + trend + seasonal + residual**

Y_t : monthly mean of tropospheric NO_2

t : months

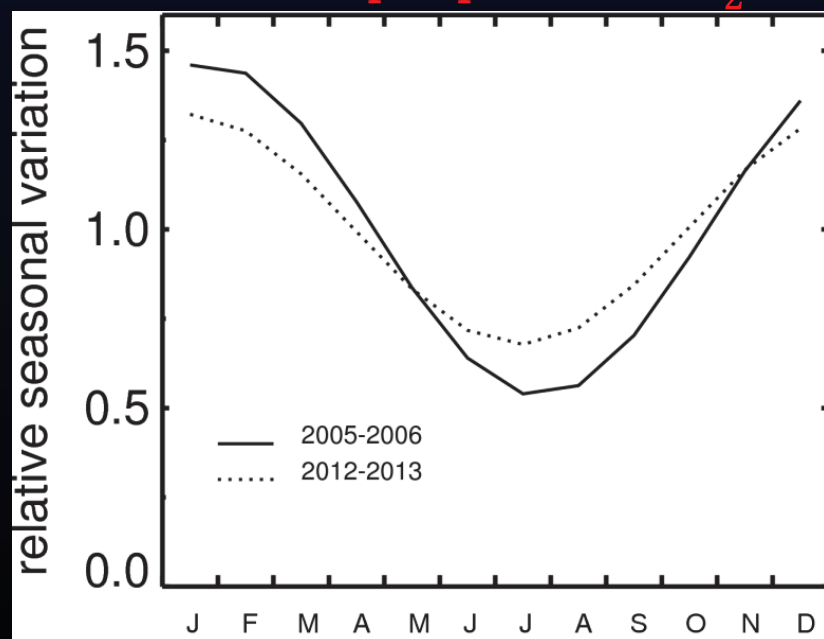
Y_0 : constant

B : monthly trend

$A1, A2$: constant defining seasonal variability

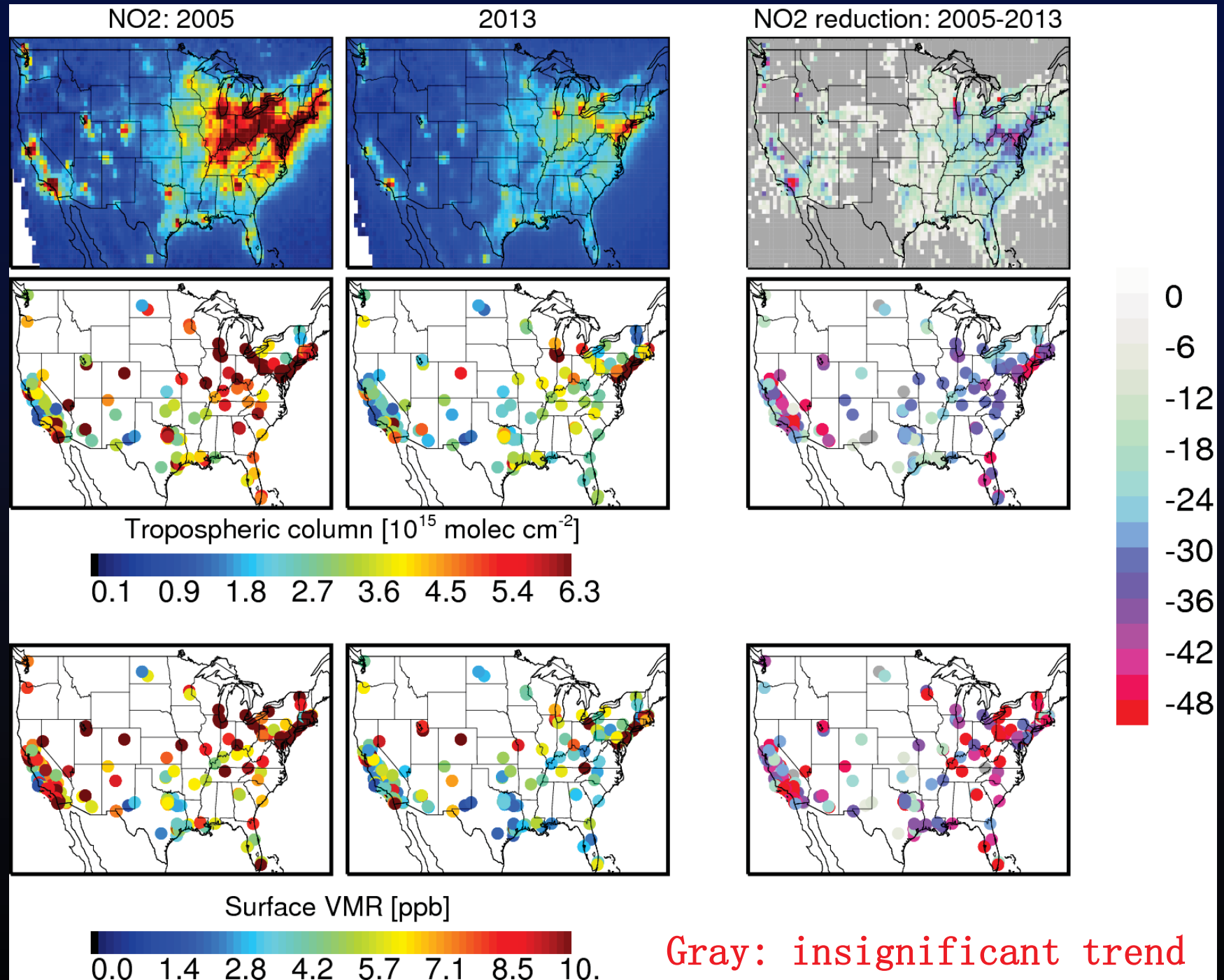
N_t : residual

OMI tropospheric NO_2

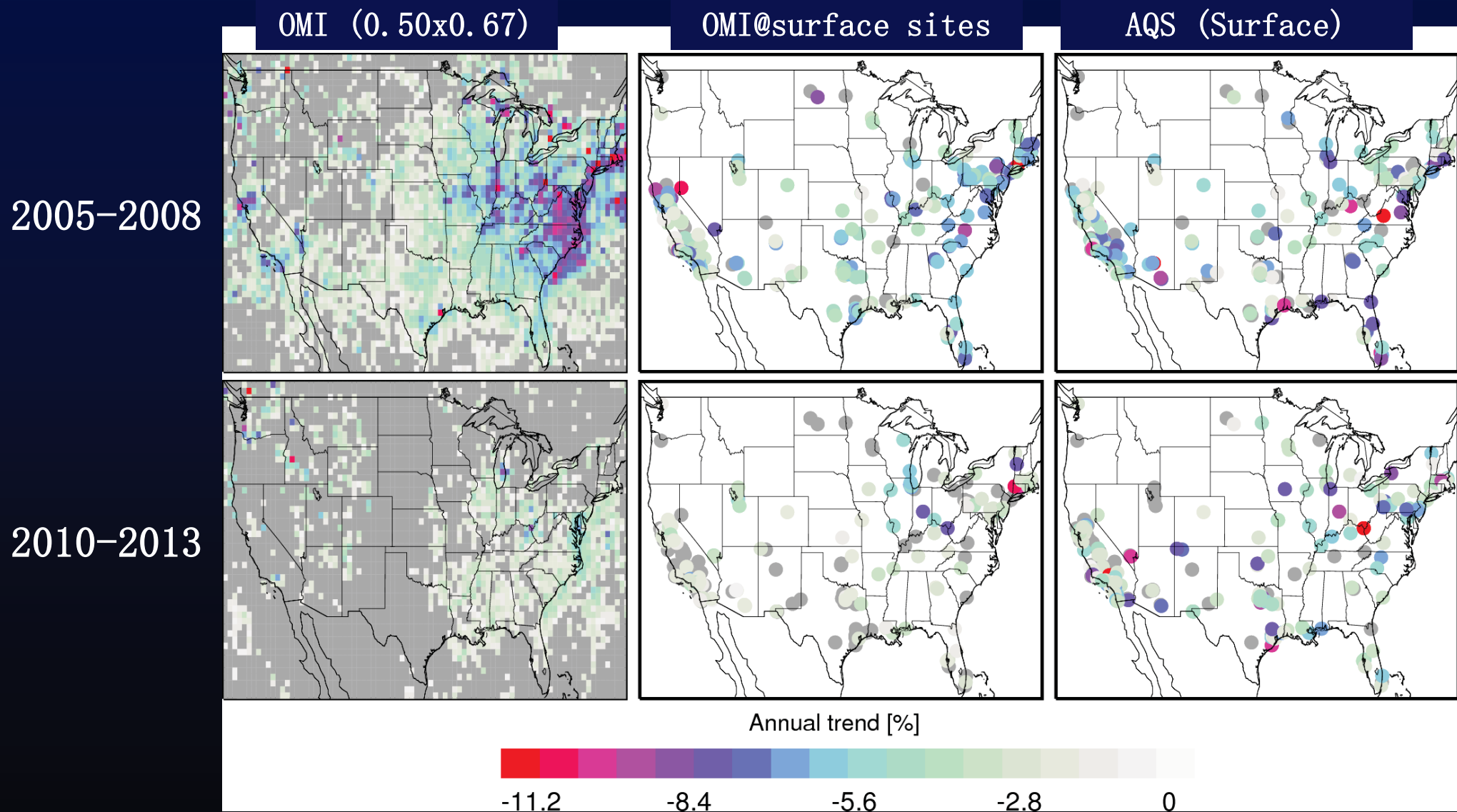


$$Y_t = \text{constant} + \text{trend} + \text{seasonal} + \text{seasonal amplitude change} + \text{residual}$$

OMI and surface (AQS) measurements show consistent trend



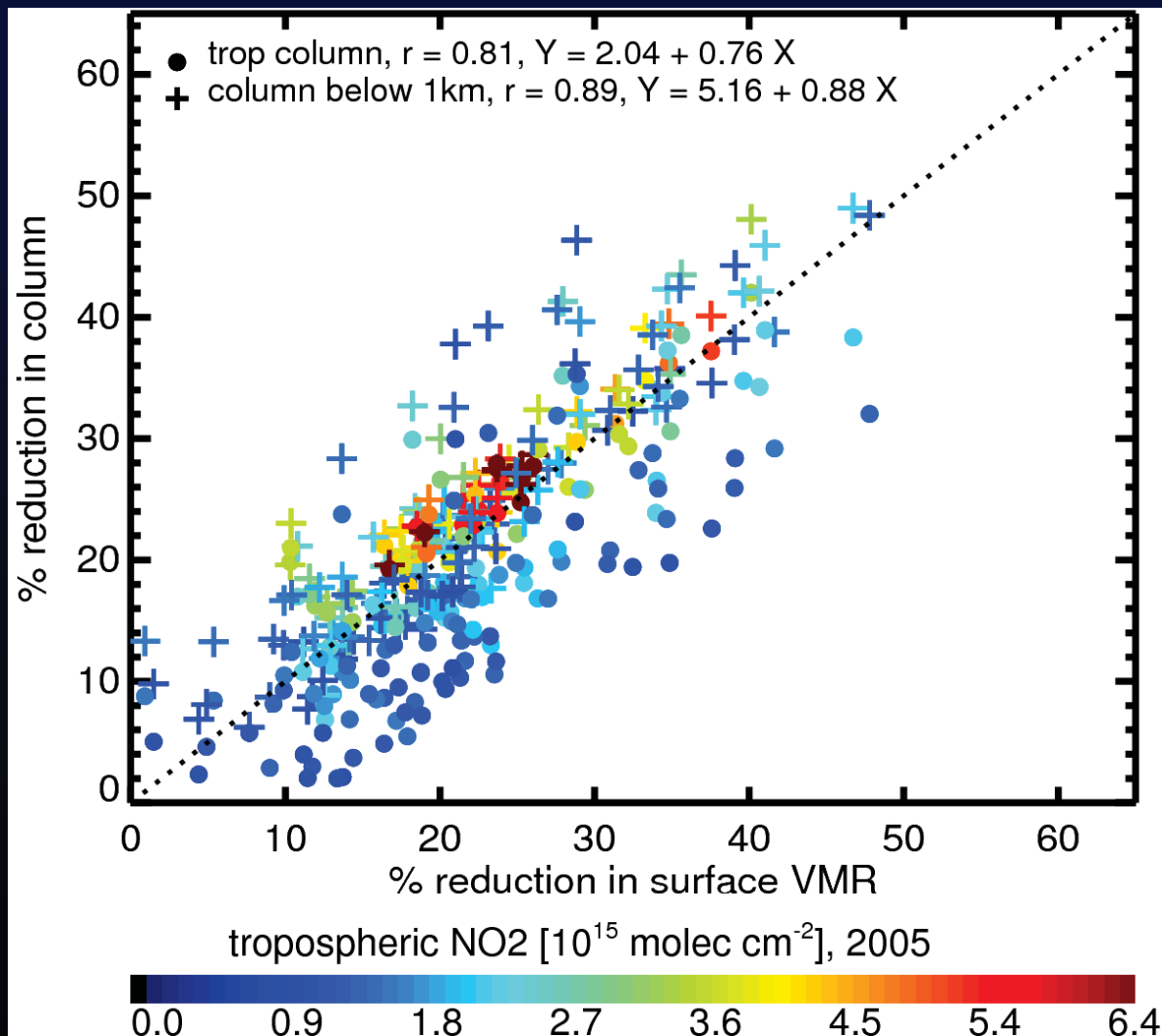
Pace of NO₂ reduction is slowing down lately



- a) OMI shows complex spatial trend that surface monitors cannot provide,
b) For 2005–2008, large and significant trend, c) Pace of reduction is slowing down
- Gray: insignificant trend

Causes for the difference: (A) Do we expect NO₂ column and surface concentration exhibit same trend?

Results from model simulation
2005–2010

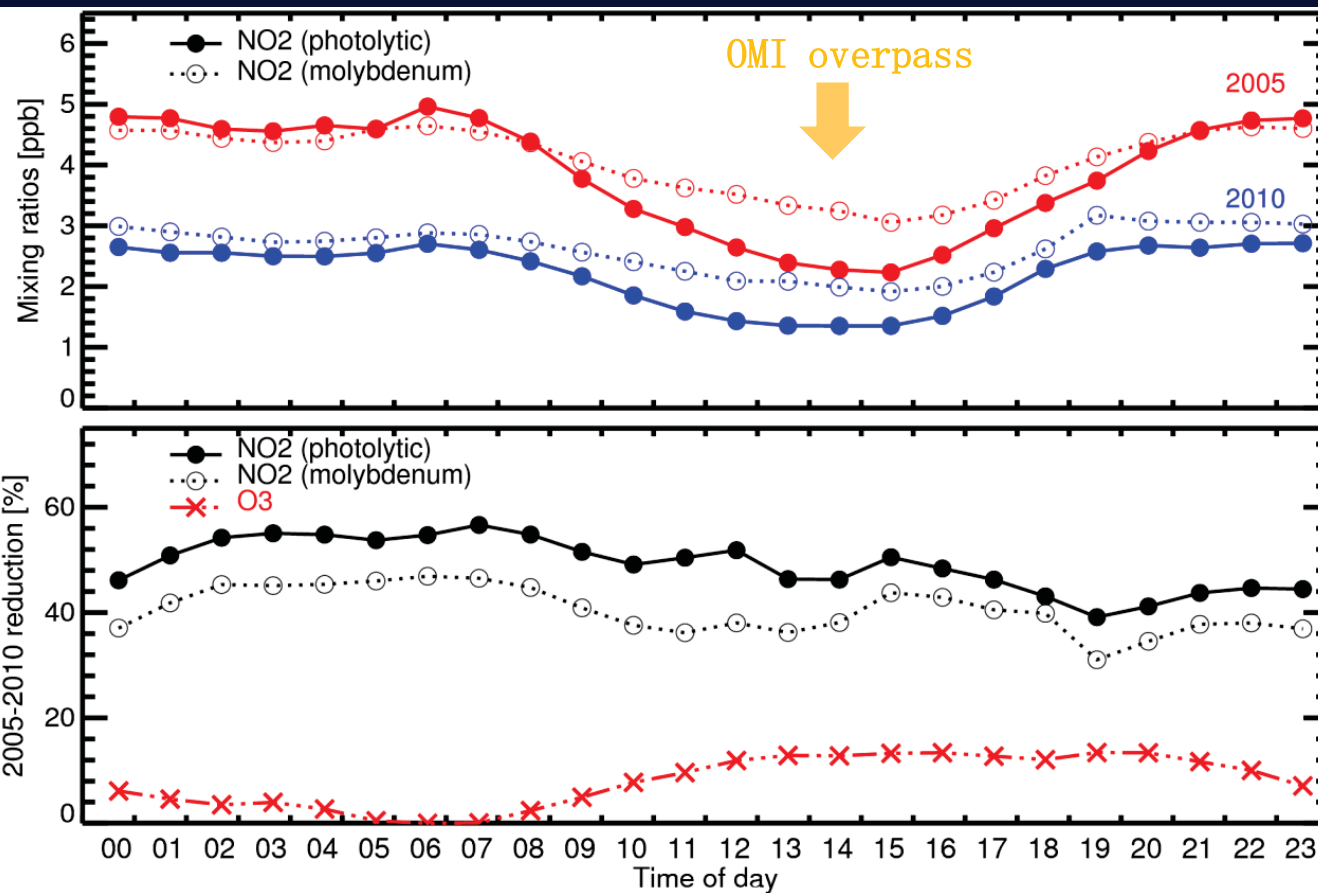


- NO₂ column and surface concentration don't necessarily feel same trend
- In less polluted areas, trend in surface concentration are higher than in column
- In highly polluted areas, trends are similar

Causes for the difference: (B) Do AQS monitors offer actual NO_2 trend?

NO_2 measurements at Yorkville, GA
2005–2010

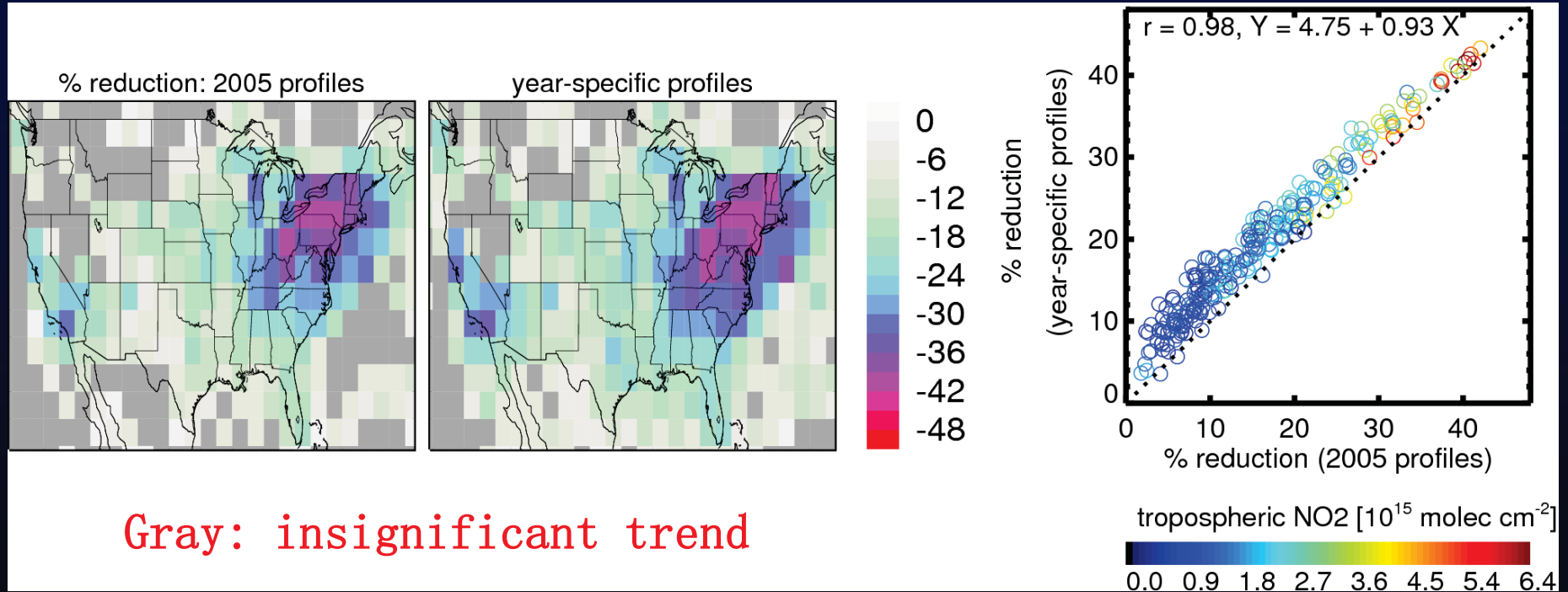
Photolytic NO_2 (SEARCH): True NO_2
Molybdenum NO_2 (AQS): $\sim \text{NO}_x$
(reactive nitrogen species)



- Strong interference around OMI overpass
- Interference is growing as NO_2 levels going down
- AQS monitors likely underestimate true NO_2 trend

Causes for the difference: (C) How do a-priori NO₂ profiles used in retrievals affect OMI-derived trend?

Separate NO₂ retrievals with 2005 and year-specific monthly mean profiles: OMI NO₂ trend for 2005–2010



- Profiles with updated emissions result in increase in both magnitude and areas of significant trend
- Trends are less sensitive to a-priori in highly polluted areas
- Satellite-observed NO₂ trends are likely underestimated due to the use of profiles with outdated emissions

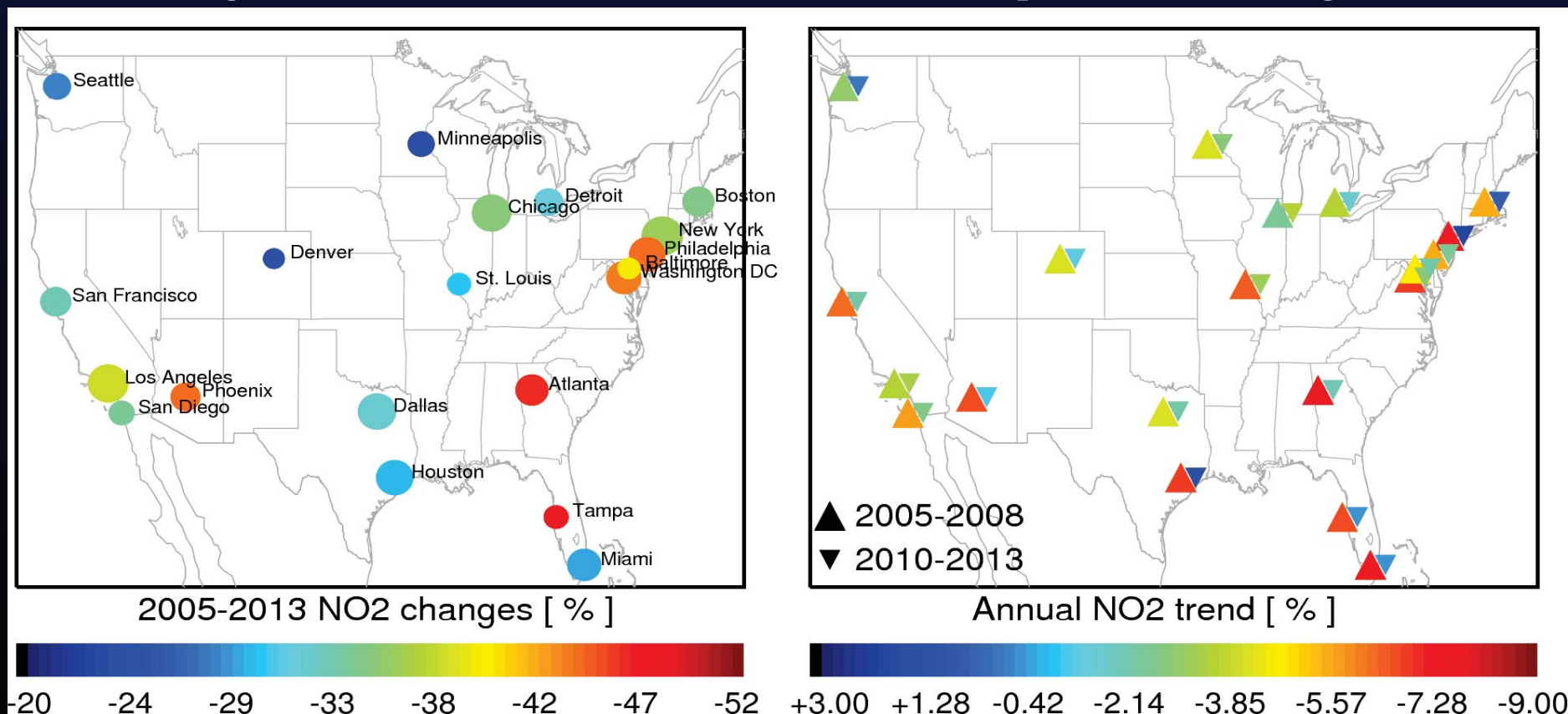
Satellite-observed NO_2 trends over top-20 metro areas

In highly polluted areas, satellite-observed NO_2 trends
[A] are least affected by a-priori,
[B] are close to surface concentration trends,
[C] offer true NO_2 trend

OMI trend \approx actual surface trend over metro areas and power plants

Change for 2005–2013

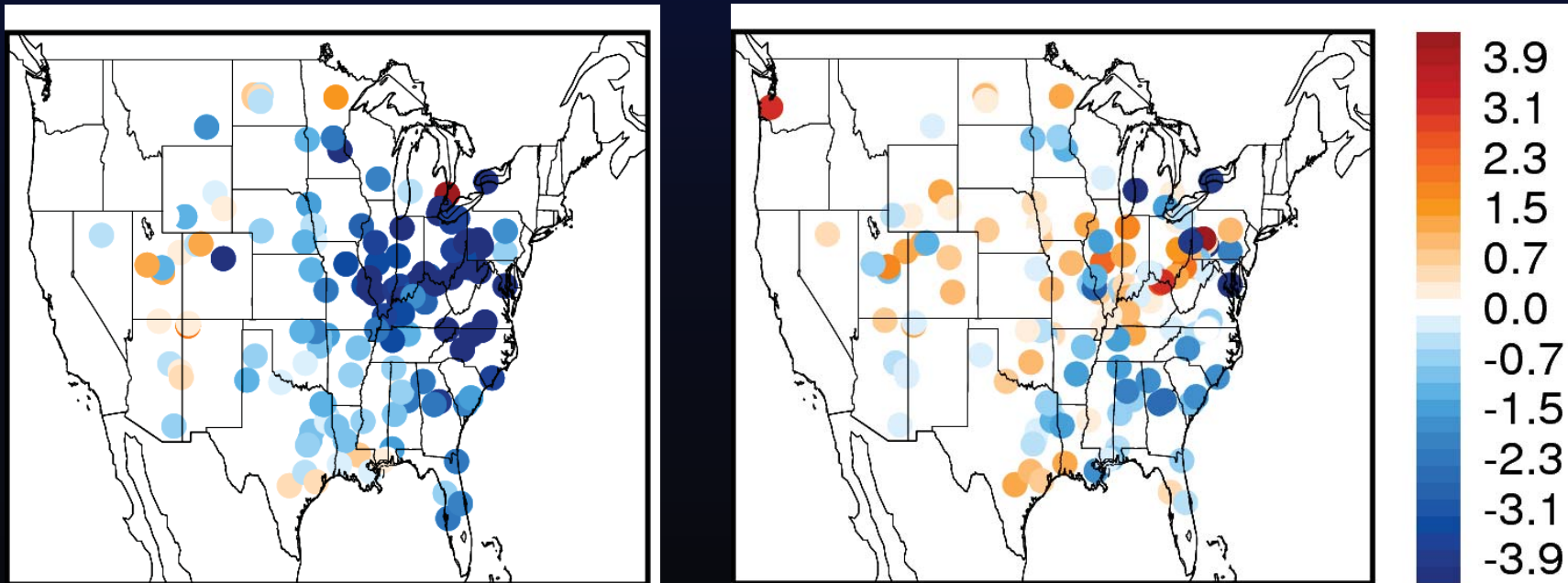
Annual pace of change



Trends over top-100 power plants

Since ~2009, because of certain legal complications, many power plants could comply without running their control devices.

OMI annual NO_2 trend (10^{14} molec cm^{-2})
2005–2009 2010–2014



Increasing trend confirmed by CEMS data

Conclusions

- NO₂ trends from OMI and surface monitors (EPA/AQS) are generally consistent
- The pace of NO₂ reduction is slowing down in recent years
- NO₂ column and surface concentration unlikely feel similar trend, except in highly polluted areas
- AQS (molybdenum converter) monitors may not offer actual NO₂ trend
- Satellite-derived trends are sensitive to a-priori NO₂ profiles used in retrievals
- NO₂ reductions over major metro areas range 20–50% for 2005–2013, with annual rate of 3–8% for 2005–2008 and $\pm 3\%$ for 2010–2013

Acknowledgements:

NASA, ACAST

Thank you for your attention

Analysis of time series: 2005–2013

